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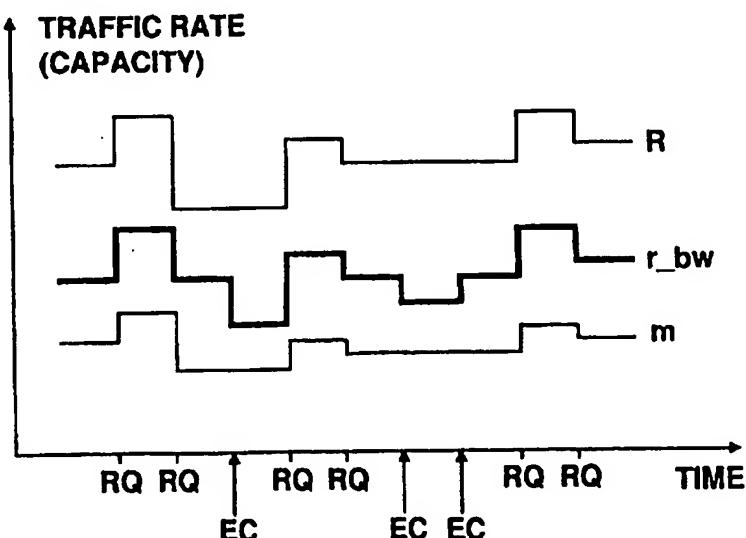
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## (54) Title: CONNECTION ADMISSION CONTROL IN HIGH-SPEED PACKET SWITCHED NETWORKS

## (57) Abstract

In a high-speed packet switched communication system such as an ATM network, the number of existing connections is limited by a Connection Admission Control (CAC) procedure. For each newly requested connection, the expected traffic rate is added to an already reserved bandwidth and a test is made whether the sum is above a given limit. According to the invention, the reserved bandwidth ( $r_{bw}$ ) is updated not only for each new connection adding the additional requested capacity (RQ), but also in-between using an effective traffic capacity value derived from measuring the actual traffic (EC). For obtaining a reasonable effective traffic capacity value, the traffic sample sequence is modified by filtering out the "noise" representing short-time variations. This is done in an iterative procedure in which the cutoff between the signal and the "noise" portion is adaptively and dynamically changed so that the available buffer capacity can accommodate just that noise portion. For the filtering process, wavelet transformation is used.



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1                   **DESCRIPTION****Connection Admission Control in High-Speed Packet Switched Networks**

5

**FIELD OF THE INVENTION**

10

This invention relates to Connection Admission Control (CAC) in a high-speed packet switched network, and in particular to a CAC method which dynamically adapts to variations in the actual observed traffic.

15

**BACKGROUND**

20                   Packet-switched networks are of increasing interest for the communication of computer data and a variety of other signals. In particular, it seems that Asynchronous Transfer Mode (ATM) networks will be widely employed in the future.

25                   ATM is a packet-oriented switching and multiplexing technique for present and future broadband communication services having a wide spectrum of traffic statistics and Quality of Service (QoS) requirements. ATM offers high bit rates and higher flexibility than Synchronous Transfer Mode (STM). Through statistical multiplexing of many individual connections onto the same link, ATM networks achieve a higher utilization of the network. On the other hand, ATM networks demand more sophisticated connection 30 admission control algorithms and congestion control methods in order to achieve the goal of a statistical multiplexing gain but still fulfilling QoS requirements.

1 Managing bandwidth in a network can be done in several different ways. In  
the following, a few approaches are presented.

5 (a) Peak Rate Allocation

10 For this method, the user specifies at connection setup only its peak rate. The network then reserves along the path on each link the requested peak bandwidth. The call is rejected if the sum of allocated bandwidths on one involved line exceeds its total capacity. The network reserves this peak rate independent of the user's actual traffic. The network monitors the peak rate of the user and polices its behavior. In case the user exceeds its negotiated peak rate, the network can take corrective actions. This method offers a high guarantee for quality of performance but it leads of course to a poor utilization of the network.

15 (b) Minimum Bandwidth Allocation

20 In this approach, the network user specifies the minimal required bandwidth that is needed for the connection. The network then reserves this amount of bandwidth on each link. A new connection is rejected if the total amount of allocated minimal bandwidth on a link would exceed the total link capacity. This method can lead to very high network utilization but a high quality of performance is not guaranteed, especially for sources with great variance in their traffic rates.

25 (c) Traffic Behavior Specification and Allocation

30 With this method, the user supplies a whole vector of parameters describing its behavior. In ATM, the vector includes peak cell rate, mean cell rate and maximum burst size. The network then tries to calculate the needed network resources for the given parameter vector. The decision to accept or refuse a connection is difficult to make in order to achieve high network utilization. There is a trade-off between performance guarantee to the user and network utilization. The statistical multiplexing of several virtual channel connections onto the same link by reserving a bandwidth below the specified peak rate can lead to overbooking of links and therefore to congestion and cell losses.

- 1 The transformation of the traffic descriptor vector into an amount of bandwidth is a key point to achieve a high network utilization.
- 5 The control functions for maintaining the required quality of service and for avoiding congestion in a high-speed packet switched network are either preventive or reactive. A preventive method is the Connection Admission Control (CAC) for new connections, reactive methods are bandwidth adaptation or transmission rate control for already existing connections (established virtual circuits).
- 10 In Connection Admission Control (also sometimes termed call admission control), a user has to make a request prior to establishment of a new connection. The respective network unit (such as a link access unit) then makes, based on the declared capacity or bandwidth which the new connection requires and on already existing bandwidth obligations, whether the new connection can be accepted. If not, the request is rejected; otherwise, sufficient bandwidth is allocated for the new connection which is then established.
- 20 Several descriptions of CAC methods are available in the prior art among which the following are of particular interest in connection with the present invention:
  - (a1) German Patent DE 4 134 476 (1993) entitled "Verfahren zur Steuerung der Zulassung von neuen Verbindungen bei asynchronen Zeitmultiplex-Paket-Vermittlungssystemen (Method of Admission Control for New Connections in Asynchronous Time Multiplex Packet Switching Systems)".
  - 30 (a2) H.Kroener et al.: "Performance Modelling of an Adaptive CAC Strategy for ATM Networks", RACE Project 2068 LACE, 1993.

1 In these two publications, a method is disclosed in which a test is made  
whether the required bandwidth for a new connection, together with the  
already allocated bandwidth for existing connections, will exceed a  
predetermined utilization limit. This limit is dynamically adapted between  
5 given minimum and maximum values. The adaptation depends on actual  
network performance, in particular the fact whether cell losses occurred or  
not. The method is based on assumed traffic rates and not on the actual  
traffic situation, and it requires notification of actual cell losses which may  
cause an undue delay for making correct admission decisions for new  
10 connections.

(a3) U.S.Patent 5 132 966 (1992) entitled "Call Control with Transmission Priority in a Packet Communication Network of an ATM Type". In the system disclosed in this patent, information sources are classified into at least two priorities. A specific bandwidth is assigned to each requesting source which is the specified peak rate for first priority sources and the specified average rate for second priority sources. A request is only accepted if the sum of the bandwidth currently assigned to all accepted sources plus the specific bandwidth of the new source does not exceed the transmission line capacity  
15 (predetermined capacity). In this system, the decision is always based on the accumulated sum of requested (reserved) capacities. This does not reflect the actual traffic situation and therefore may often lead to non-optimal utilization of the link.

25 (a4) H.Saito et al.: "Dynamic Call Admission Control in ATM Networks", IEEE Journal on SAC, Vol.9, No.7 (Sept.1991), pp.982-989. In this control method, an estimate of cell loss probability is made when a new connection request arrives. The estimate is based on count values of arriving cells and on an estimated traffic characteristic of the new connection, based on parameters  
30 specified by the user. A new connection is only accepted if the estimated cell loss probability is below a predetermined value. The method is suited essentially for a single connection only, requires complicated calculations

1 for the cell loss probability, and does not consider the influence of the ratio  
between fast and slow variations in the traffic rate.

5 The following publications describe reactive control methods for packet  
switched networks:

(b1) S.-Q. Li et al.: "Link Capacity Allocation and Network Control by Filtered  
Input Rate in High-Speed Networks", IEEE/ACM Trans. on Networking, Vol.3,  
No.1 (Feb.1993), pp.10-25. The method disclosed in this paper concerns link  
10 capacity allocation for a finite buffer system. The allocated link capacity is  
adaptively changed using an on-line observation of the filtered input rate.  
The peak input rate for the link is filtered at a properly selected cut-off  
frequency and only the low-frequency component is considered for the  
capacity allocation. Though this method eliminates the higher frequency  
15 contents of the traffic behavior to achieve an improvement, it is not optimal  
because the cut off-frequency is fixed once it has been selected so that it  
does not reflect the possible variations in the distribution between fast and  
slow changes in the traffic rate.

20 (b2) U.S.Patent 5 359 593 (1994) entitled "Dynamic Bandwidth Estimation and  
Adaptation for Packet Communications Networks". This patent discloses a  
technique for adaptively adjusting the bandwidth allocated to a source, by  
measuring the mean bit rate of signals from the source and filtering said  
mean bit rate measurements (and further by measuring and filtering loss  
25 probability), and changing the allocated bandwidth when the  
measured/filtered values are not within given limits. The filtering is done for  
determining the actual mean bit rate of the incoming traffic. Beside being  
specified only for a single source, this method does not consider adaptation  
to changing proportions between fast and slow traffic rate variations  
30 (changing signal/noise ratio) so that it may not be optimal for links serving a  
large number of sources.

## OBJECT OF THE INVENTION

5 It is an object of present invention to devise a method for Connection Admission Control which is flexible and adaptive to varying traffic situations. More particularly, the object is a CAC method which can react immediately to new connection requests but adapts also very fast to variations in the traffic pattern. It is a further object to find a CAC method which can be easily implemented and executed on normal signal processing equipment.

## SUMMARY OF THE INVENTION

15 The invention for achieving these objects is a method for Connection Admission Control in a high-speed packet switched network, in which a request for a new connection or for an expansion of bandwidth is accepted or rejected in dependence of the newly required transmission capacity and the already reserved transmission capacity. The invented method comprises the following steps: The actual traffic capacity is measured regularly to obtain traffic capacity samples; for a window of such samples, the higher frequency portion of a signal representing the sequence of samples is separated by an iterative and adaptive transform operation, such that this higher frequency portion does not exceed a given relation to available buffer capacity; from the remaining lower frequency portion which is obtained after a reverse transform operation, an effective traffic capacity value is determined; and this effective traffic capacity value is used as the basis for connection admission control procedures.

30 Preferably, the transformation operation for filtering the traffic sample sequence is a wavelet transformation. For the CAC procedure, a reserved bandwidth value is preferably maintained which is updated, using a declared rate value, whenever a new connection is established, but which is

1    also updated whenever a new value of the effective traffic capacity is made  
available.

5    The main advantages of this novel CAC method are that it allows to  
optimize utilization of a link (or other resources involved), by adapting  
relatively fast to traffic variations which may be extreme, thus allowing to  
accept as many new connections or bandwidth requests as possible but on  
the other hand restricting connection admissions fast if necessary, to thus  
10    avoid degradation of quality. It also enables to adapt selectively to long-time  
traffic variations without reacting to various degrees of short-time variations  
in the traffic behavior. By appropriate selection of the transformation  
function used for the filtering process employed for obtaining the actual  
effective traffic capacity, it can be ideally adapted to specific traffic  
15    characteristics of a network. Further, the method is applicable to different  
forms of networks and aggregations of communication resources, and is  
particularly suited for ATM systems.

#### BRIEF DESCRIPTION OF THE DRAWINGS

20

A detailed description of a preferred embodiment of the invention is given  
in the sequel to allow a better understanding of its principles and  
advantages, in connection with the following drawings:

25    *Fig. 1*    is a block diagram of a link access unit in which present  
invention is employed;

30    *Figs. 2A and 2B* are diagrams showing the course of traffic rate values over  
time, and showing a curve of the reserved bandwidth on which,  
according to the invention, the Connection Admission Control  
is based, together with accumulated (aggregate) peak and  
mean rates based on user declarations. In particular, the figure  
illustrates the changes (adaptation) in reserved bandwidth due

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1 to new user requests as well as those due to new measurement  
values of actual traffic;

5 *Fig. 3* is a flow diagram of the process steps (procedure) for  
determining whether a new connection can be accepted, and  
for the adaptation of the reserved bandwidth when a new  
connection is actually accepted;

10 *Fig. 4* is a flow diagram illustrating the process steps for adapting the  
reserved bandwidth when a new value for the effective (actual)  
traffic capacity becomes available as a result of actual traffic  
measurements;

15 *Fig. 5* illustrates overlapping sampling windows of traffic samples for  
calculating sequential values of the effective traffic capacity;

20 *Fig. 6* is a block diagram of the wavelet transformation process used  
in the embodiment of the invention;

25 *Fig. 7* illustrates the time localization in the frequency domain of a  
wavelet transformation;

25 *Fig. 8* is a flow diagram of the procedure for calculating a new value  
of the effective traffic capacity on the basis of a window of  
traffic samples (measurement values);

*Figs. 9A-9D* illustrate for a traffic curve the filtering effect which is achieved  
by wavelet transformation and by modification of the resulting  
set of coefficients.

1

## DETAILED DESCRIPTION

5 In the presented embodiment of the new CAC method, periodical frequency-domain analyses of traffic measurements on a link are made to obtain an effective traffic capacity value that is representative for the actual 10 long-term traffic. A function representing the sequence of traffic measurement values is transformed into the frequency domain spectrum using an appropriate method, in particular wavelet transformation. The spectrum is then separated into a signal portion (low frequencies) and a noise portion (high frequencies). The threshold between low and high 15 frequencies is chosen in an iterative adaptive process such that the noise can be absorbed in the link buffer. This means that the maximum of the cumulative sum of the high frequencies must only fill a given fraction the link buffer. From the remaining low frequency portion, the effective traffic capacity is then obtained as the maximum of the amplitude during the considered interval (the window).

20 Fig.1 is a block diagram of a communication unit employing the invention. Input 11 is connected to one output of a switch which furnishes packets that are to be transmitted over a link 13 to the next node or switch of the system. It is assumed in this example that the system is an Asynchronous Transfer Mode (ATM) network so that the packets which are to be transmitted are 25 ATM cells. The cells received at input port 11 are stored in a buffer 15 which is implemented as leaky bucket which transfers cells under control of output means 17 to the link.

30 As the link has a limited transmission capacity, any new connection or increase of bandwidth of an already existing connection has to be accepted or rejected by the Connection Admission Control (CAC) which is effected by the remaining portions of the unit shown in Fig.1.

A resource manager (RM) receives requests for connection admission or bandwidth expansion from attached users on input 21, and in response to

1 such request issues either an Accept or a Reject signal to the respective  
2 user on output 23. It can further send control information over connection 25  
3 to output means 17 for adjusting the output rate (leak rate) of buffer 15. The  
4 requests from users to the resource manager include at least the values of  
5 expected peak traffic rate  $R$  and expected mean traffic rate  $m$ .

10 A sampler 27 does periodic traffic measurements by counting the cells  
11 transferred into buffer 15. The samples generated by sampler 27 consist of  
12 the cell counts divided by the period length  $\Delta t$ . (In an efficient  
13 implementation, the cell counts can be used directly because the division is  
14 a linear scaling which can also be applied afterwards.) The sampling  
15 frequency depends on the link speed and the buffer size. It is determined by  
16 the resource manager.

17 The sampler feeds its output to a digital signal processor (DSP) 29. In  
18 periodic intervals, the DSP analyzes the samples and calculates the effective  
19 traffic capacity which it sends to the resource manager RM. The resource  
20 manager triggers respective analyzing and calculation operations in the  
21 DSP. A queue manager (QM) 31 is provided which monitors the queue  
22 length in buffer 15. If the queue length exceeds a certain threshold or if  
23 even cell losses occur, it signals this fact to the resource manager.

24 Requests for termination of a connection or a decrease in bandwidth which  
25 are also sent from users to the resource manager (RELEASE, on input 21)  
26 and which also indicate the released peak and mean rates ( $R, m$ ) are always  
27 granted. They are required however for adapting the current value of the  
28 reserved bandwidth (which will be explained later).

29 It should be noted that in connection with Fig.1 only a simple and basic  
30 embodiment of the invention is described. For this case, it is assumed that  
31 there is only one instance of the connection access control of the present  
32 invention. In general, multiple instances that control groups or individual  
33 connections can be present. Some connections can be completely excluded

1 from the method. For instance, for a connection with a burst generation rate  
larger than the window size that is used for measurements and effective  
capacity calculation, simple peak rate allocation can be done. Furthermore,  
since the description is given for an ATM network, all the traffic parameters  
5 are given in cells per second. In case of variable size packets the method  
can still be used by expressing the parameters in bits per second.

#### Traffic and Bandwidth Values

10 For a better understanding of some terms used in this description, Figs.2A  
and 2B are provided. The curve in Fig.2A shows the course of the traffic rate  
(number of cells per time unit) over time. The curve can be considered as  
the sequence of measurement values which the sampler obtains when it  
counts the transmitted cells per chosen time increment. This curve shows  
15 that there are slow variations in the traffic capacity (low frequency contents  
of the curve) which are to be considered for access control and bandwidth  
reservation, and short-time variations (high frequency contents of the curve)  
which can be absorbed by the buffers. The average rate of the traffic, i.e. its  
mean value, is indicated by the dashed line  $m$ , and the peak value is  
20 indicated by  $R$ .

Fig.2B schematically shows that the reserved bandwidth ( $r_{bw}$ ) is kept  
between the aggregate mean rate  $m$  and the aggregate peak rate  $R$ . It is  
adapted with each user request (at time  $RQ$ ) for new bandwidth or release  
25 of granted bandwidth, and is also adapted whenever the calculation of a  
new, measurement-based effective traffic capacity value  $c$  is made (at time  
 $EC$ ). The reserved bandwidth is always limited in the range between the  
total (aggregate) requested mean rate  $m$  and the total (aggregate) requested  
peak rate  $R$  (even if the measurement-based effective capacity value is  
30 outside of this range). Details will be shown later.

It should be noted that the calculation of a new effective capacity value (and  
thus an updating of the reserved bandwidth) can be either made at regular

1    intervals (as shown later) or whenever considered necessary, e.g. when a  
2    service quality degradation (cell loss etc.) is notified from the queue  
3    manager QM to the resource manager RM. The latter procedure is assumed  
4    for Fig.2B (irregular intervals for EC). A combination of both would also be  
5    possible.

#### Handling of Request for New Connection

10   The procedure for handling a request for a new connection (or for the  
11   request for a bandwidth increase) by the resource manager is now  
12   described in connection with the flow diagram of Fig.3. At any point in time,  
13   there is a currently reserved bandwidth  $r_{bw}$ , aggregate peak rate  $S_R$  (sum  
14   of all requested and accepted peak rates), and aggregate mean rate  $S_m$   
15   (sum of all requested and accepted mean rates). For the link which has to  
16   transmit the traffic exists a link speed  $l_{speed}$  (maximum traffic that can be  
17   transmitted), and a link utilization factor  $l_{util}$  which is typically 0.8. This  
18   factor ensures that a safety margin of e.g. 20% of the link capacity remains.

20   When the idle resource manager RM receives a request, A in Fig.3,  
21   including the values for expected peak value  $R$  and mean value  $m$  of the  
22   traffic rate for the new connection, it first checks B, in Fig.3, whether the  
23   sum of the currently reserved bandwidth  $r_{bw}$  and the new peak rate does  
24   not exceed the link speed times link utilization factor. If the sum is too large,  
25   the new request is immediately rejected, C in Fig.3. Otherwise, the  
26   acceptance procedure is effected. The aggregate peak value  $S_R$  and mean  
27   value  $S_m$  are increased by the respective values  $R$  and  $m$  of the new  
28   request, D and E in Fig.3. Then, the reserved bandwidth is adapted. First,  
29   the peak rate  $R$  is added to the old reserved bandwidth to obtain a  
30   provisional new value for  $r_{bw}$  which is then bounded between the new  
31   aggregate peak rate  $S_R$  and the new aggregate mean rate  $S_m$ , F and G in  
32   Fig.3. The result then is the actually new reserved bandwidth  $r_{bw}$ .

- 1 The reason for bounding the reserved bandwidth between total (aggregate) mean and peak rates ( $S_m$  and  $S_R$ ) is because these values are the theoretical boundaries. If the traffic goes over the total peak rate there is something wrong with the policing of the peak rate. In case the traffic is 5 permanently below the total mean rate the sources did not specify themselves well. This kind of false description (self-specification) should be detected and corrected at the access to the network (and is not part of the method of the invention).
- 10 When the new reserved bandwidth is fixed, the output rate for the buffer 15 is adapted,  $H$  in Fig.3, to a value which is equal to the sum of this new  $r_{bw}$  plus the link reserve mentioned above which is  $l_{speed}*(1-l_{util})$ . This new output rate is signalled to output means 17. Finally, an acceptance signal is furnished through output 23 to the requesting user  $l$  in Fig.3. The resource 15 manager is then available for the next operation.

Essentially the same procedure is executed when a connection is terminated (or a bandwidth decrease is requested). The only differences are that no acceptance or rejection is signalled (because termination/decrease is 20 always accepted), and the new aggregate peak and mean rates are established by subtracting  $R$  and  $m$  from the previous aggregate rates  $S_R$  and  $S_m$ . The new reserved bandwidth is then also obtained by subtracting  $R$  from the old  $r_{bw}$  and bounding it between the new aggregate mean and peak rates.

25

#### Adaptation of Reserved Bandwidth to Effective Capacity

An important feature of the presented Connection Admission Control 30 method is the fact that the reserved bandwidth is not only based on the input values  $R$  and  $m$  of the requesting users (as described so far) but that regular measurements of the actual traffic rates (cell rates) are made, that the high-frequency contents of the resulting curve are eliminated in an

- 1      iterative, adaptive process, and that on the basis of the lower frequency contents of this curve of traffic rates an effective traffic capacity is calculated at regular intervals. The reserved bandwidth is adapted on the basis of each new effective capacity value.
- 5      Elimination of the higher frequency contents of the traffic measurement values with the aid of wavelet transformation, and computation of effective capacity values will be explained in a later section. In the following, adaptation of the reserved bandwidth is described with reference to Fig.4.
- 10     Beside obtaining a new effective capacity value at regular intervals (described later) or when considered necessary (as mentioned above), the resource manager also stores the actual aggregate peak rate value  $S_R$  at regular intervals as value "save\_S\_R". When a new reserved bandwidth is to
- 15     be calculated, a recent change in the aggregate peak rate  $S_R$  can then also be considered. This is done because the effect of a recently added new connection may not yet be appropriately reflected in the window of measurement samples on which the calculation of  $c$  is based.
- 20     The procedure is shown in the flow diagram of Fig.4. When a new effective capacity value "c" becomes available, A in Fig.4, the difference between the stored old aggregate peak value  $old\_S_R$  and the then actual aggregate peak value  $S_R$  is obtained (B in Fig.4). A provisional new reserved bandwidth  $r_{bw}$  is then determined as the sum of the actual effective capacity  $c$  and the obtained difference  $\Delta S_R$  between peak values (C in Fig.4). The reserved bandwidth is then bound between the aggregate peak cell rate and aggregate mean cell rate but at most to the link speed multiplied by the link utilization (D, E, and F in Fig.4). Finally, the buffer output rate is set to the newly determined reserved bandwidth plus the link reserve (G in Fig.4).
- 30

To summarize, the resource manager RM maintains a current value of reserved bandwidth  $r_{bw}$  which it dynamically adapts. An adaptation is

1 made: (a) on the basis of user estimates (traffic rate specifications), each  
time a user requests new bandwidth or releases bandwidth; and (b) on the  
basis of actual traffic measurements from which an effective traffic capacity  
is calculated at regular intervals. The admission of a new connection (or a  
5 bandwidth increase) is always based on the current value of the reserved  
bandwidth  $r_{bw}$ .

#### Timing of Calculations

10 In the resource manager, two timers periodically generate timeouts. The first triggers the saving of the currently allocated total (aggregate) peak rate  $S_R$  as "save\_S\_R". The second timer is to trigger a new calculation of the effective traffic capacity "c".

15 The effective capacity is calculated on partial overlapping windows, cf. Fig.5. The overlap is needed to capture trends across the borders as well. Two more things can be seen from Fig.5.

20 First, the black dots represent the points in time where the currently allocated peak rate is stored as "save\_S\_R". In the given example the middle of the window has been chosen. From such a point on until a newly calculated value "c" of the effective capacity becomes available, peak rate allocation is done for new connections or bandwidth increases. This is to cope with increases that arrive towards the end of the window and which 25 can only be observed in a short period. The closer this freezing point is moved towards the beginning of the window the more pessimistic the algorithm is (longer observation phase).

30 The second point is the time delay (the little arrows) until the result of a new calculation becomes available. This delay is also the limit for the triggering of new calculations.

1 A reasonable window size is between one and several seconds. The larger  
the window is chosen the more observations from the past influence the  
future.

5 **Wavelet Transformation**

For the frequency analysis to be made in the present invention when the  
effective traffic capacity is calculated, wavelet transformation is the most  
appropriate tool, though other forms of transformation could also be  
10 applied. However, as it is actually only used as a tool, no detailed  
description will be given here. Good introductions and theoretical  
background can be found in the following publications:

- 15 – Amara Graps: An Introduction to Wavelets. IEEE Computational  
Science and Engineering, Vol.2, No.2, Summer 1995. IEEE Computer  
Society, Los Alamos.
- Charles K. Chui: An Introduction to Wavelets. Wavelet Analysis and its  
Applications, Vol.1. Academic Press, Boston 1992.
- Stephane G. Malat: A Theory for Multiresolution Signal Decomposition:  
20 The Wavelet Representation. IEEE Transactions on Pattern Analysis  
and Machine Intelligence, Vol.11, No.2, July 1989, pp.674-693.

25 A brief explanation of wavelet transformation is given in the following to  
help understanding of the described embodiment of the invention which  
uses wavelet analysis and synthesis.

30 Wavelet analysis can be compared to Fourier analysis. It transforms a signal  
from the time domain into the frequency domain. In case of a Fourier  
analysis, one is either in the time domain or in the frequency domain but  
there is no relationship between the two domains. This means that in the  
frequency domain it can be seen which frequencies appeared and how  
strong they are represented but it is not possible to see where (in the time  
domain) they appeared. To cope with this problem, a windowed Fourier

1 analysis can be used where the input signal is split into different windows  
which are then analyzed individually. The difficulty of this approach is how  
the window borders have to be handled. The wavelet analysis solves this  
problem by looking at the input signal at different scales or resolutions. On  
5 a large scale, the focus is on gross features i.e. trends, while on a small  
scale minor features (e.g. the noise) are of interest.

10 The general idea is to adopt a wavelet prototype function, called an  
"analyzing wavelet" or a "mother wavelet". These functions are bases in the  
function space. Compared to a Fourier transformation, where only one basis  
consisting of sines and cosines of different frequencies exist, one has the  
choice of numerous bases. This allows to find the best basis for a particular  
input data set.

15 Temporal analysis is carried out with a contracted high-frequency version of  
the mother wavelet. The frequency analysis is done with a dilated  
low-frequency version of the prototype wavelet.

20 Similar to the Fast Fourier Transformation (FFT) exists a Fast Wavelet  
Transformation (FWT). Instead of FWT it is sometimes called Discrete  
Wavelet Transformation (DWT). The FFT has a complexity  $O(n \log 2)$  while  
the FWT can be calculated in  $O(n)$ . For both transformations, the input  
length is expected to be a power of 2. In Fig.6, a block diagram of the  
procedure is given. "g" and "h" designate the specific selected wavelet filter  
25 functions. The  $\downarrow 2$  stands for a down-sampling of 2. This is achieved by  
dropping every second sample of the input. The high-pass filtered output  
on each scale is kept as the coefficients of that scale. The low-pass filtered  
and down-sampled output is fed back as input to the transformation  
process. This process is sometimes called "pyramid algorithm" because of  
30 the hierarchical processing. The loop is performed until no samples are left.  
On each scale the number of coefficients is reduced by a factor of 2. The  
total number of coefficients over all scales equals the number of input  
values. The low-pass filtering is to smooth the signal while the high-pass

- 1 filtering is to reveal the details. In wavelet theory, the mother function for the low-pass filter is called the "scale function" and the mother function for the high-pass filter "wavelet function".
- 5 The most striking difference between Fourier and wavelet transformation is that the wavelet functions are localized in space and frequency. Sines and cosines do not have both of these properties. Because they are periodic, non-vanishing functions, they are only localized in frequency. This two-fold localization very often generates a sparse spectrum of coefficients, a
- 10 property that is desired in many applications such as image compression or noise removal in time series.

To illustrate the two-fold localization, the following example with 16 samples is given (cf. Fig.7). On the first scale, the coefficients  $c_1$  to  $c_8$  are generated. Then on the second scale,  $c_9$  to  $c_{12}$  are generated. The bracketing in Fig.7 indicates the localization for the calculated coefficient. The region is given through the down-sampling operation that contracts the data in each iteration by a factor of two. Unlike to the Fourier transformation, one sees to which part of the input data the coefficient belongs. In most implementations, the coefficients are put in one vector one scale after the other, the last coefficient being the final residual of the low-pass filtering. The total number of coefficients is then equivalent to the input sample size.

For the wavelet transformation, there are numerous possible bases already known. Wavelets are classified into several distinct families. Inside the family a further distinction is made according to the number of coefficients. For the wavelet analysis to be carried out when an effective capacity value is calculated according to this invention, a suitable basis is the Haar wavelet which is a special member of the Daubechies wavelet family. Suitable filters of this family would be e.g. filters of either length 2 or length 16. An important property of the Daubechies family is that the wavelet itself has a self-similar structure. This is of advantage when the curve representing the traffic rate values also has self-similar properties which can often occur in

- 19 -

1 packet switched networks (bursts appear over a wide spectrum of time  
scales).

#### Computation of Effective Traffic Capacity

5 As was mentioned above already, the effective traffic capacity is computed  
(in the present example) at regular intervals, based on actual traffic  
measurements of the sampler. The respective algorithm is now explained  
with reference to the flow diagram of Fig.8. It should be noted, however, that  
10 this algorithm is only one possible implementation; alternatives will be  
mentioned later.

The following parameters (variables) are used in the algorithm:

15 **found**  
binary control variable indicating whether the higher  
frequency portion separated from the traffic signal  
fulfills a given criterion. It is either FALSE  
(binary zero) or TRUE (binary one);

20 **step**  
a number indicating the step or scale which has been  
reached in the iterative algorithm;

20 **nr\_of\_steps**  
the total number of steps (scales) which can be  
made in one execution of the algorithm;

25 **coeffs**  
a set of coefficients which are obtained by wavelet  
transformation of a traffic signal. The set can be  
modified to extract a desired frequency portion of  
the signal (filtering).

25 **X**  
set or window of traffic rate values which are obtained  
by the sampler;

wt (...)  
indicates a wavelet transformation;

iwt (...)  
indicates the inverse of a wavelet transformation;

30 **high\_f**  
filtered higher frequency portion of a traffic signal;

- 20 -

```
1      low_f
      filtered lower frequency portion of a traffic signal;

      modify (coeffs, step)
      modification of the coefficients set by extracting (eliminating)
      a portion of the coefficients depending on the respective step
      number;

5      cumsum (...)
      for a given window of measurement values, providing for each point
      (of time) the cumulated sum of all preceding values; the cumsum is
      also a curve (sequence) of values for the respective window;

      max_dev
      the maximum (positive) value of the cumsum function in a
      given window;

10     c
      effective traffic capacity as determined by this algorithm.
```

Before explaining the algorithm in detail, a short general description is given here. The goal is to separate from the traffic signal the lower frequency portion for which bandwidth must be reserved, from the higher frequency portion which represents rapid short time variations in the traffic capacity that can be absorbed by the buffers.

In an iterative process, a varying higher frequency portion is separated from the traffic signal and a test is made whether that portion can be absorbed by the buffers. If yes, the portion is modified and another test is made and so on until the highest possible portion is found which can be absorbed. The remaining lower frequency portion of the traffic signal is then used for determining the effective traffic capacity.

Referring to Fig.8, the algorithm is started by a timer signal (START\_CALC). Then some variables are set to their initial values (A in Fig.8): found = FALSE (binary zero), step = 0, and high\_f = 0. Thereafter (B) a wavelet transformation is made to obtain a set of coefficients, with the following parameters: X is the current window of traffic samples from the sampler; h and g are the wavelet filter functions (as explained above); and the nr\_of\_steps which depends on the number of values contained in the

1 window of traffic samples  $n=2^{nr\_of\_steps}$ , where n is the number of sample  
values).

5 Then a test is made (C in Fig.8) whether the control variable is still FALSE  
and whether the current step number is yet below the total possible number  
(nr\_of\_steps). If both answers are positive (as is the case in the first  
iteration), the step number (initially zero) is increased by 1 (D). The set of  
10 coefficients is then stored as new\_coeffs (E in Fig.8) on which the following  
operations are made. Thereafter (F) the current set of coefficients  
(new\_coeffs) is modified according to the current step number. By this  
operation, a portion of the coefficients is cancelled (e.g. one half of all  
coefficients are eliminated). This operation effects a filtering, i.e. the  
remaining coefficients represent only some higher frequency portion of the  
traffic signal. Some details will be explained in connection with Fig.9.

15 In the next process step, the current high-frequency portion is stored as  
high\_f\_old (G in Fig.8) so that it can be used later in the final branch of the  
algorithm. In the first iteration, both are still zero. Thereafter (H), an inverse  
20 wavelet transformation is made to obtain the higher frequency portion  
high\_f that has been filtered out in the current iteration. Following  
parameters are used in this inverse transformation: the current modified set  
of coefficients new\_coeff; the filter functions rh and rg for the inverse  
transformation; and the current step number. The filtered higher frequency  
25 portion is now available as a sequence of traffic rate values (a window)  
which are distributed around zero.

Then, the following operations are made (I in Fig.8). A cumulated sum curve  
(cumsum) is computed by determining for each point of time in the window  
the sum of the respective and all previous traffic rate values. Each value in  
30 this curve represents the buffer filling (above or below a mean filling) which  
is due to the rapid variations in traffic capacity, i.e. due to the higher  
frequency portion. The highest (positive) value of this cumsum curve (i.e.

- 22 -

1 the maximum filling of the buffers above the mean filling) is then detected as  
5 max\_dev.

Then, a test is made (J in Fig.8) whether this value is already above a value  
5 which is given as the product of the buffer capacity times a utilization factor.  
Such utilization factor depends of course on the particular network and the  
general nature of the traffic. A typical value would be 0.1. If the max\_dev is  
still small enough to be absorbed by the buffers (output FALSE of test) then  
the higher frequency portion can be extended in the next iteration. If,  
10 however, the max\_dev was too large (output TRUE of test), then the limit  
was reached, the control variable found is set to TRUE (binary one), and the  
previous higher frequency portion (high\_f\_old) of the traffic signal must be  
used for the effective capacity determination.

15 Returning to the first operation in the iteration loop (C in Fig.8), when the  
respective test reveals that either the control variable is TRUE (limit  
reached), or that the final step had been made (which means that all  
coefficients have been eliminated and the total traffic signal is higher  
frequency which can be absorbed by the buffers), then a branch is made to  
20 the final operations of the iterative process. The values which were stored  
as high\_f\_old are subtracted from the values X representing the window of  
the total traffic signal, to obtain the set of values low\_f which are the lower  
frequency portion that actually represents the longer-term traffic capacity (L  
in Fig.8). Then, the maximum of this set of values is taken as the effective  
25 traffic capacity c (M). This value c is transferred to the resource manager  
RM (N in Fig.8) and can then be used for a new calculation of the reserved  
bandwidth, as shown in Fig.4.

#### Modification of Wavelet Transformation Coefficient Set

30

Fig.9 illustrates the result of modifying the set of coefficients (the wavelet  
vector) for filtering out certain frequency components from a signal. The first  
curve, A in Fig.9, shows the original signal. The second curve, B, is the

1 result of the wavelet transformation, i.e. the set (vector) of coefficients  
obtained as output. For modification, a portion determined by the respective  
scale (step number of algorithm), e.g. the lower quarter of the set of  
5 coefficients, is maintained while the other portion, i.e. the upper three  
quarters in this example, are dropped (set to zero). The thus modified  
wavelet vector (i.e. the selected subset of coefficients) is shown as curve C  
in Fig.9. By an inverse wavelet transformation process on this modified  
vector, one obtains a reconstructed signal, D in Fig.9. The wavelet functions  
used for this example were Daubechies of size 16.

10

If the result of the modification, i.e. the reconstructed signal does not meet  
given conditions, then in a next step another modification can be made.  
Starting from the same wavelet vector, B in Fig.9, another subset of  
15 coefficients would be selected, e.g. by eliminating one half of the coefficients  
and retaining the other half (result would be a different modified vector than  
that shown at C in Fig.9). Thereafter, another reconstructed signal would be  
obtained by an inverse wavelet transformation, and again this can be  
subjected to the criterion test.

20

While in the example illustrated in Fig.9 higher frequencies were eliminated  
by filtering, in the effective capacity calculation described above (flow  
diagram of Fig.8), higher frequency components of the signal are extracted  
by modifying the coefficient vector. This is done by selecting coefficients  
from the upper portion (one half or one quarter, etc.).

25

Different strategies may be used for modifying the wavelet vector in an  
iterative process to finally obtain a reconstructed signal which best fits the  
given criterion. In the procedure for effective capacity calculation explained  
30 with Fig.8, in the first step the smallest higher frequency portion is selected,  
and in subsequent iterations the portion is stepwise increased until the  
given criterion is met. Another possibility is to use a binary strategy (like in  
a binary search). In this case, the first vector modification would be made to  
set the cutoff in the middle of the total range. In the next iteration, the vector

- 1 modification would be so chosen that the cutoff is in the middle of the previously selected half of the range, and so forth. By this strategy, the final result might be faster approached.
- 5 A further possibility is to do an interpretation directly on the coefficients so that an inverse transformation is not required after each iterative step. The process then is: Do one wavelet transformation, interpret and modify the coefficients, and finally do the back transformation to obtain the lower frequency portion.

10

#### Further Advantages and Possibilities of Signal Analysis by Wavelet Transformation

With different types of wavelet bases, it is possible to drive the speed for the noise detection and separation from the signal. Compared to a Fourier transformation, the wavelet transformation is a lot more adaptive because it removes the high frequencies only at the spots where they appear. By applying weighted filters also the intensity of the noise can be captured. Strong deviation will automatically be counted to the signal and thus will influence the effective capacity.

In addition, wavelets are one of the best tools to analyze self-similar structures because they analyze a signal on different scales. Because high-speed network traffic has manifested self-similar correlation structures, wavelets are highly appropriate in this context.

#### Selection of Sampling Speed for Traffic Measurements

To enable a signal/noise separation where the noise is absorbed in the buffer, the sampling frequency must be high enough to capture a potential buffer filling between two sampling points. Therefore, the maximum number of cells that arrive in the time between two measurement points must be below the buffer capacity. On the other hand, one wants to obtain more

- 25 -

1 detailed information on the cell arrival process. As a conclusion, the  
sampling frequency must be a fraction of the buffer size. For a 155 Mbit/s  
link, a sample about every ms is a good value; this corresponds to a  
maximum of 365 cells which is about 1/3 of an often used buffer size of 1000  
5 cells.

#### Changing Utilization Factor when Quality Changes

10 The queue manager monitors periodically the buffer. In case a certain "high  
water mark" is reached or even cell losses occur, it signals this fact to the  
resource manager. The RM then reduces the buffer utilization factor thus  
making the CAC more "pessimistic" in the sense that the allocation strategy  
converges to peak rate allocation. A typical multiplication factor is 1/2.

15 After a certain period of time has passed without any lost cell, the QM  
signals this to the RM. The link buffer utilization is then increased. A typical  
multiplication factor is 1.05 which increases the link utilization by 5%. In  
general the reduction factor should be more drastic than the increase factor  
in order to avoid strong oscillation. However, it should be noted that only on  
20 high speed links the cell loss rate can be used to drive a CAC algorithm,  
because only on a high speed link this parameter can be measured with  
good confidence in a reasonable time interval.

1

## CLAIMS

- 5 1. Method for Connection Admission Control (CAC) in a high-speed packet switched network, in which a request for a new connection or for a bandwidth expansion is accepted or rejected in dependence of the newly required transmission capacity and the already reserved transmission capacity,  
said method comprising the following steps:
  - 10 – regularly measuring the actual traffic rate to produce sequential samples representing a traffic signal,
  - separating, for a window of such samples, in an iterative and adaptive signal transformation operation, a high frequency portion of the traffic signal, and changing, preferably in each iteration, said separated high frequency portion until a given condition is satisfied,
  - 15 – determining from the remaining low frequency portion of the traffic signal an effective capacity value.
  - and using this effective capacity value as a basis for the connection admission control procedure.
- 20 2. The method according to claim 1, including the following steps:
  - maintaining a reserved bandwidth value ( $r_{bw}$ ) representing the already reserved transmission capacity,
  - updating said reserved bandwidth value
    - 25 a. when a request for a new connection is accepted, by adding the peak traffic rate ( $R$ ) specified for this new connection to the current reserved bandwidth value, and
    - b. when a new effective capacity value ( $c$ ) becomes available, by deriving the reserved bandwidth value from the new effective capacity value.

- 1        3. The method according to claim 2, including the following step:
  - limiting the resulting new reserved bandwidth value ( $r_{bw}$ ) between two given limit values ( $S_R, S_m$ ).
- 5        4. The method according to claim 1, in which said separating and changing step includes the following steps:
  - preferably in each iteration, accumulating sequential values of the currently separated high frequency portion to obtain a sequence of cumulative sum values (cumsum), and
  - 10      — testing whether the maximum value (max\_dev) of said sequence of cumulative sum values is beyond a value representing buffer capacity (buffer\_util \* buffer\_size).
- 15      5. The method according to claim 1, wherein the signal transformation operation is a wavelet transformation.
- 20      6. The method according to claim 1, including the following steps for the separating operation:
  - a. transforming a window of samples into a set of coefficients by a wavelet transformation;
  - b. extracting a subset of said set of coefficients to effect a selective filtering operation for separating a high frequency portion from the traffic signal, retransforming the extracted subset of coefficients into a test window of samples, and comparing a maximum value derived from this test window with a predetermined buffer capacity value to detect whether a given relation is satisfied;
  - 25      c. depending on the test result, either
    - c1. repeating step b. by extracting another, modified subset of coefficients, or
    - c2. subtracting the contents of the appropriate test window of samples from the original window of samples, to obtain a filtered window of samples representing a low frequency portion of the traffic signal, and
- 30

- 1       d. obtaining a new effective capacity value (c) by setting it equal to  
the maximum value in this filtered window of samples.
- 5       7. The method according to claim 1, in which
  - a new value for the effective capacity (c) is obtained in regular intervals, and
  - sequential values of the effective capacity (c) are obtained for overlapping windows of traffic capacity samples.
- 10      8. The method according to claim 1, including the following steps:
  - watching buffer activity to obtain a quality loss indication when cell losses or buffer overfilling occur, and
  - determining a new value for the effective capacity (c) whenever a quality loss indication is obtained.
- 15      9. The method according to claim 2, including the following steps:
  - obtaining an estimated peak rate value (R) and an estimated mean rate value (m) with each request for a new connection or a bandwidth expansion,
  - 20     — accumulating the peak rate values and mean rate values from all accepted connection requests, to obtain an aggregate peak rate value (S\_R) and an aggregate mean rate value (S\_m), and
  - restricting each new reserved bandwidth value (r\_bw) between two limits given by the two aggregate values.
- 25      10. The method according to claim 9, including the following steps:
  - registering the current aggregate peak rate value (S\_R) at regular intervals as old aggregate peak rate value (save\_S\_R),
  - for updating said reserved bandwidth (r\_bw) in accordance with step b. of claim 2, setting the reserved bandwidth value to the sum of the new effective capacity value (c) and the old aggregate peak rate value (save\_S\_R), and then restricting the new reserved bandwidth value between the two limit values.

1

11. The method according to claim 2, including the following step:

- obtaining a buffer output rate control value (out\_rate) by adding to each new reserved bandwidth value (r\_bw) a given margin value.

5

12. Apparatus for executing Connection Admission Control (CAC) in a high-speed packet switched network, in which a request for a new connection or for a bandwidth expansion is accepted or rejected in dependence of the newly required transmission capacity and the already reserved transmission capacity,

10

said apparatus comprising:

- means (27 in Fig.1) for regularly measuring the actual traffic rate to produce sequential samples representing a traffic signal,
- means (29 in Fig.1; B...K in Fig.8) for separating, for a window of such samples, in an iterative and adaptive signal transformation operation a high frequency portion of the traffic signal, and changing, preferably in each iteration, said separated high frequency portion until a given condition is satisfied,
- means (29 in Fig.1; L, M in Fig.8) for determining from the remaining low frequency portion of the traffic signal an effective capacity value, and
- means (19 in Fig.1) for using this effective capacity value as a basis for the connection admission control procedure.

25

13. The apparatus according to claim 12, including:

- means (19 in Fig.1) for maintaining a reserved bandwidth value (r\_bw) representing the already reserved transmission capacity, and
- means (D...G in Fig.3; B...F in Fig.4) for updating said reserved bandwidth value

30

- 30 -

- 1        a. when a request for a new connection is accepted, by adding  
              the peak traffic rate (R) specified for this new connection to  
              the current reserved bandwidth value, and
- 5        b. when a new effective capacity value (c) becomes available, by  
              deriving the reserved bandwidth value from the new effective  
              capacity value.

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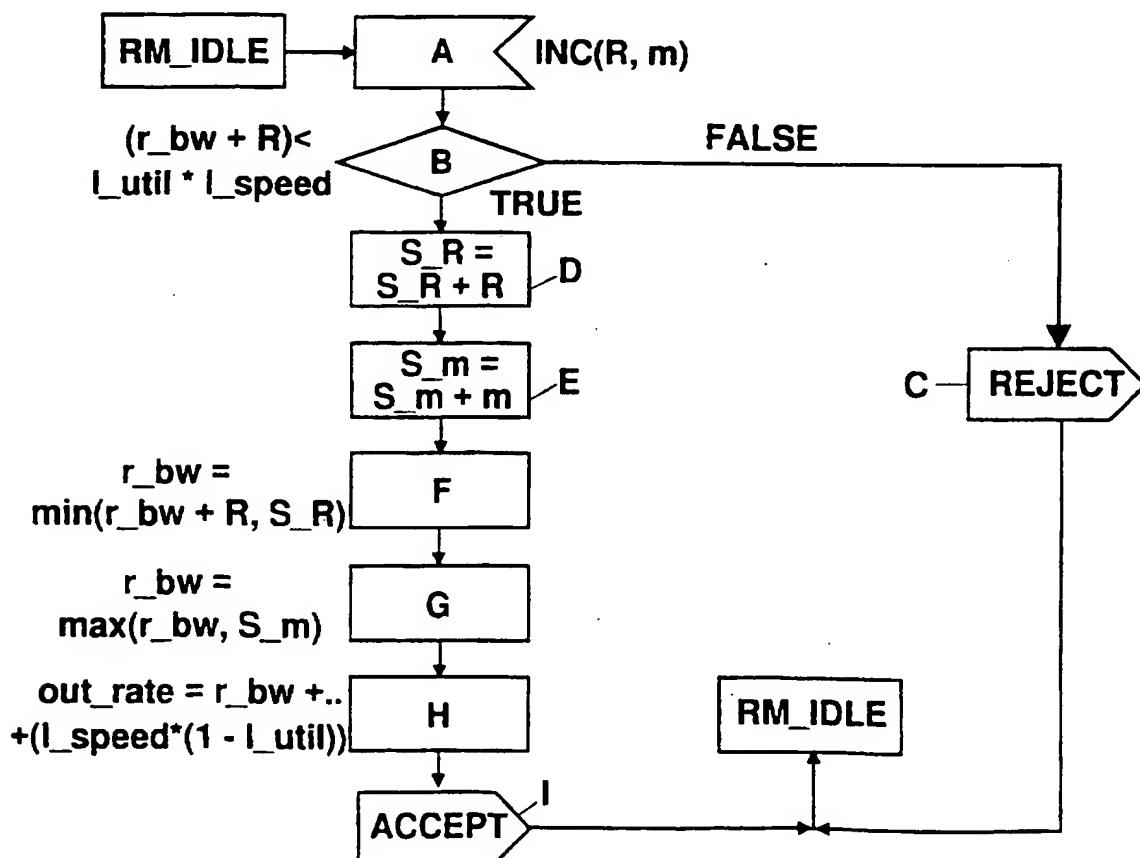
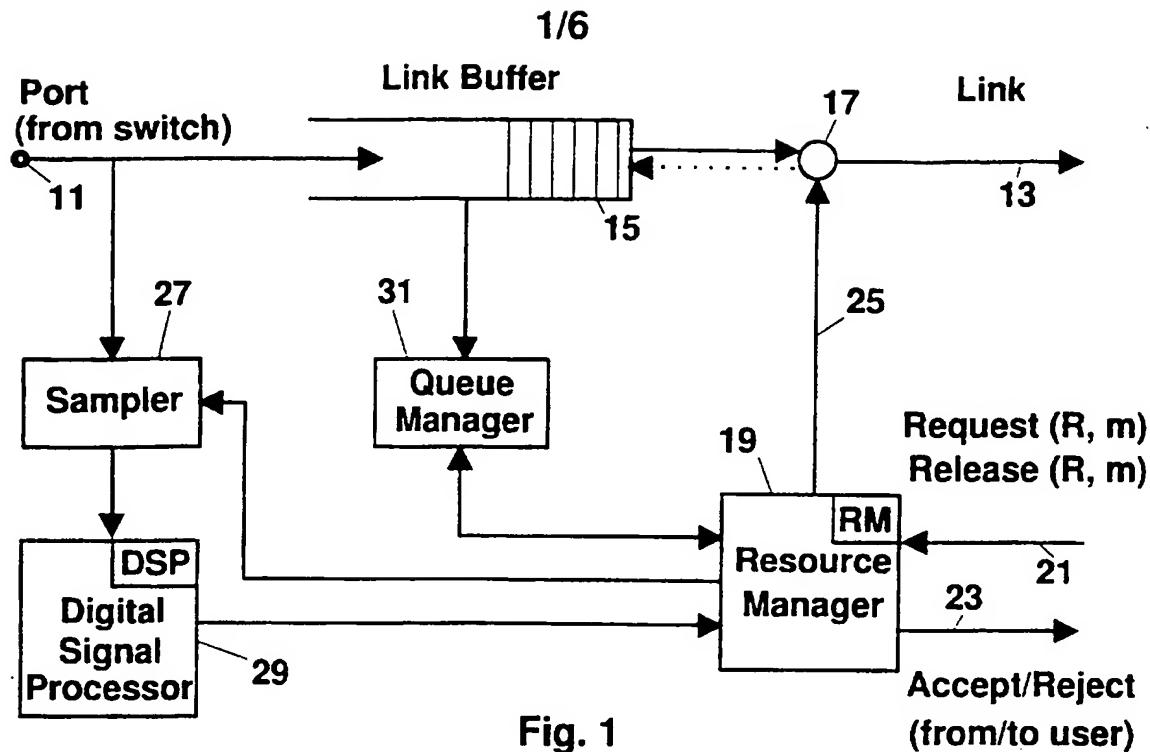


Fig. 3

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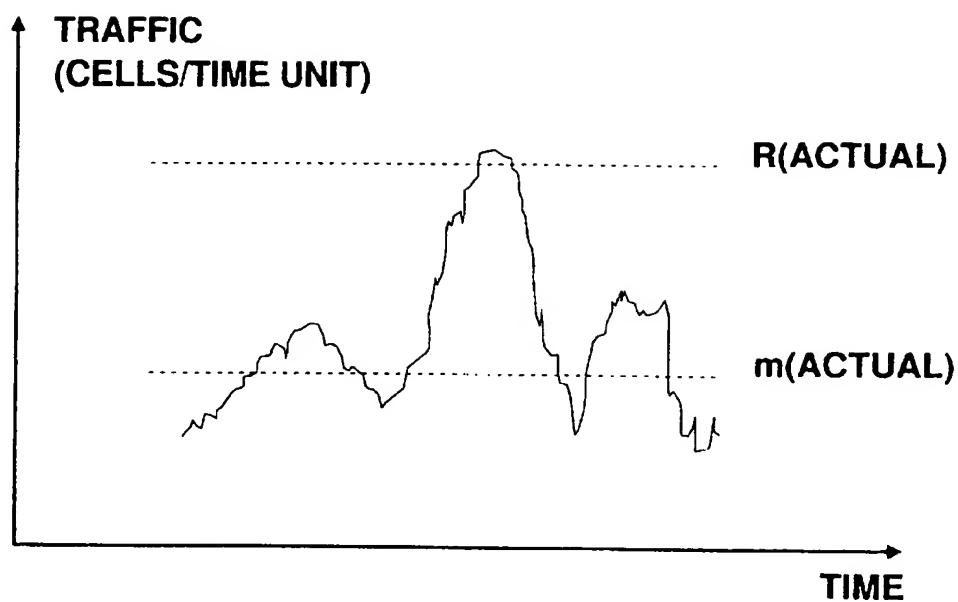


Fig. 2A

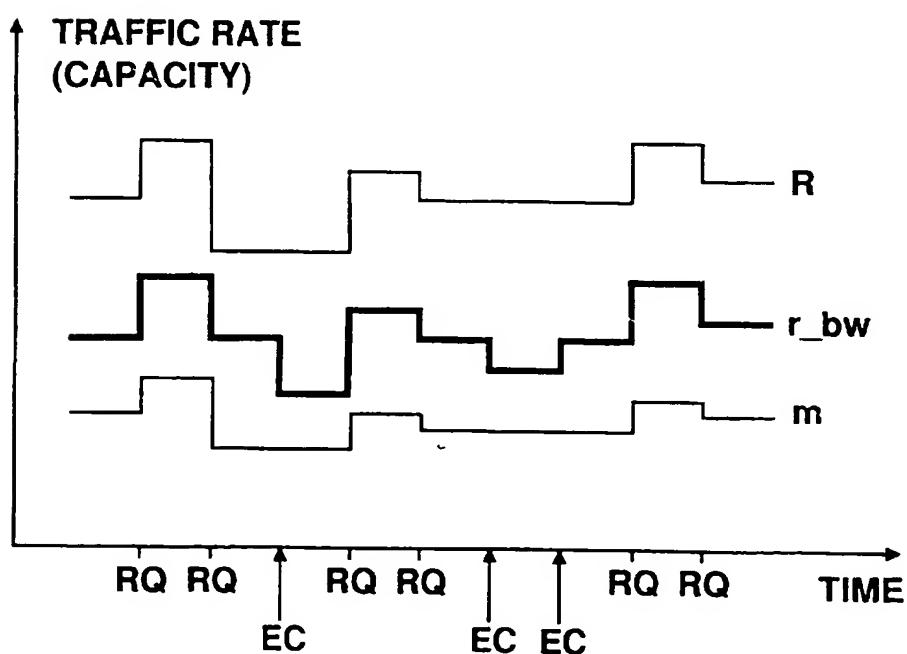


Fig. 2B

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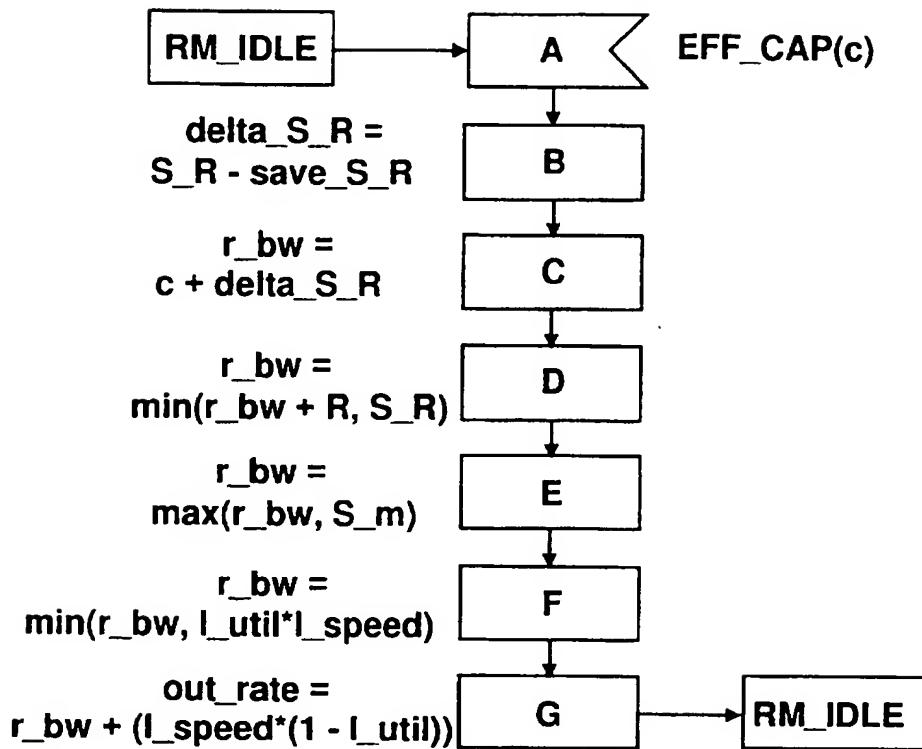


Fig. 4

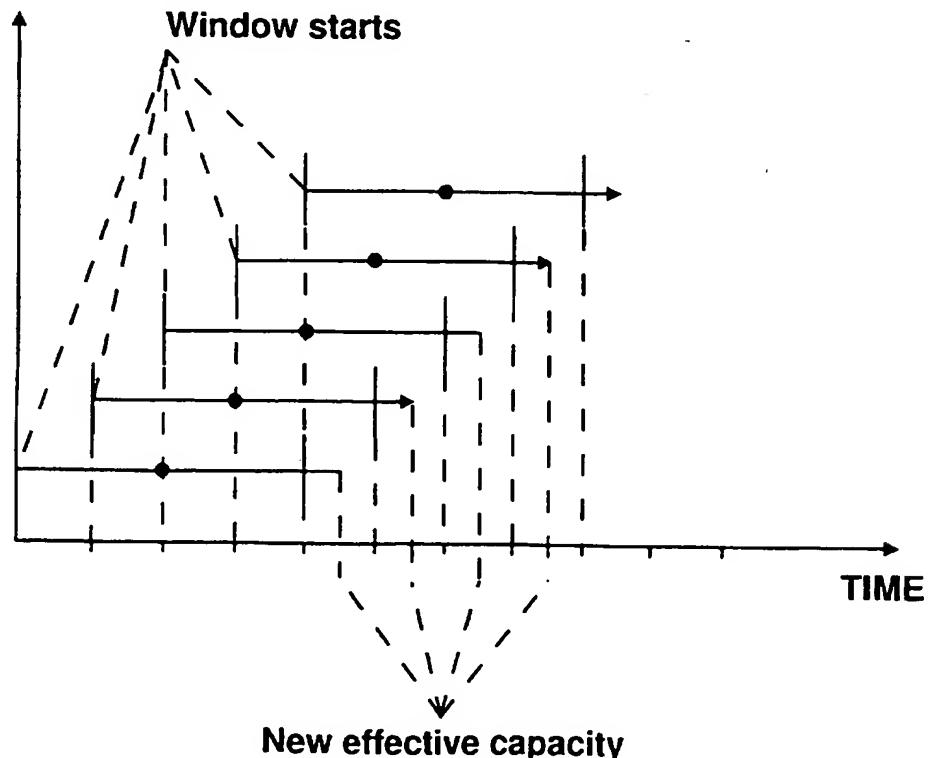


Fig. 5

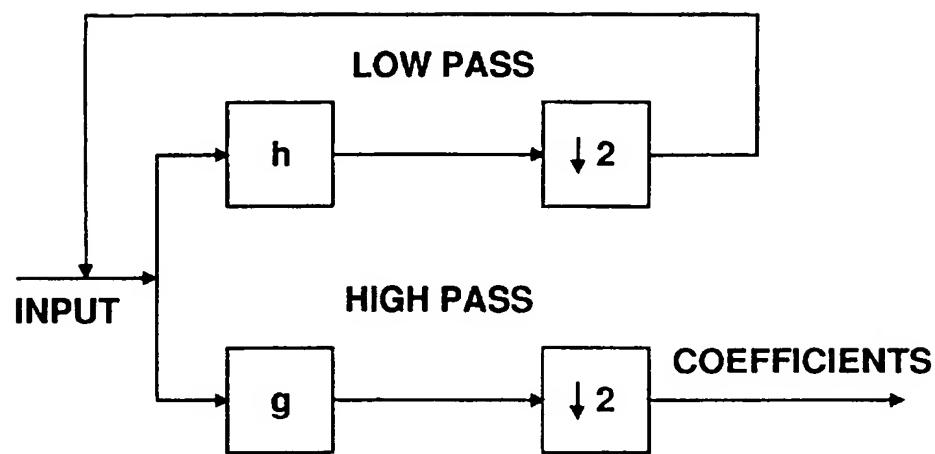


Fig. 6

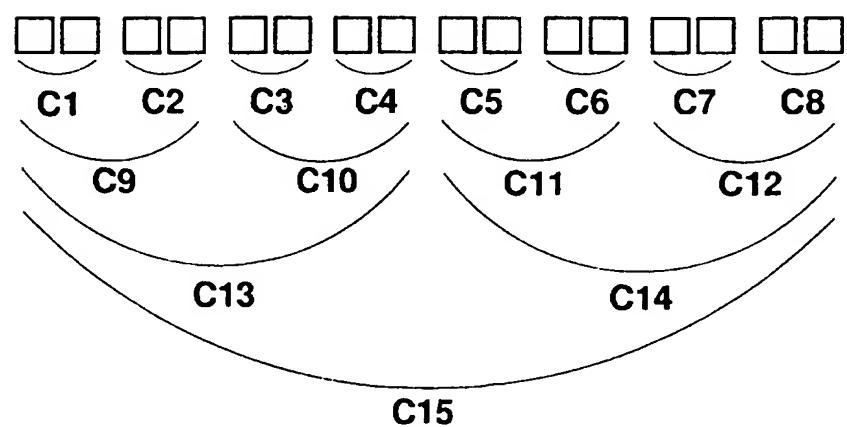


Fig. 7

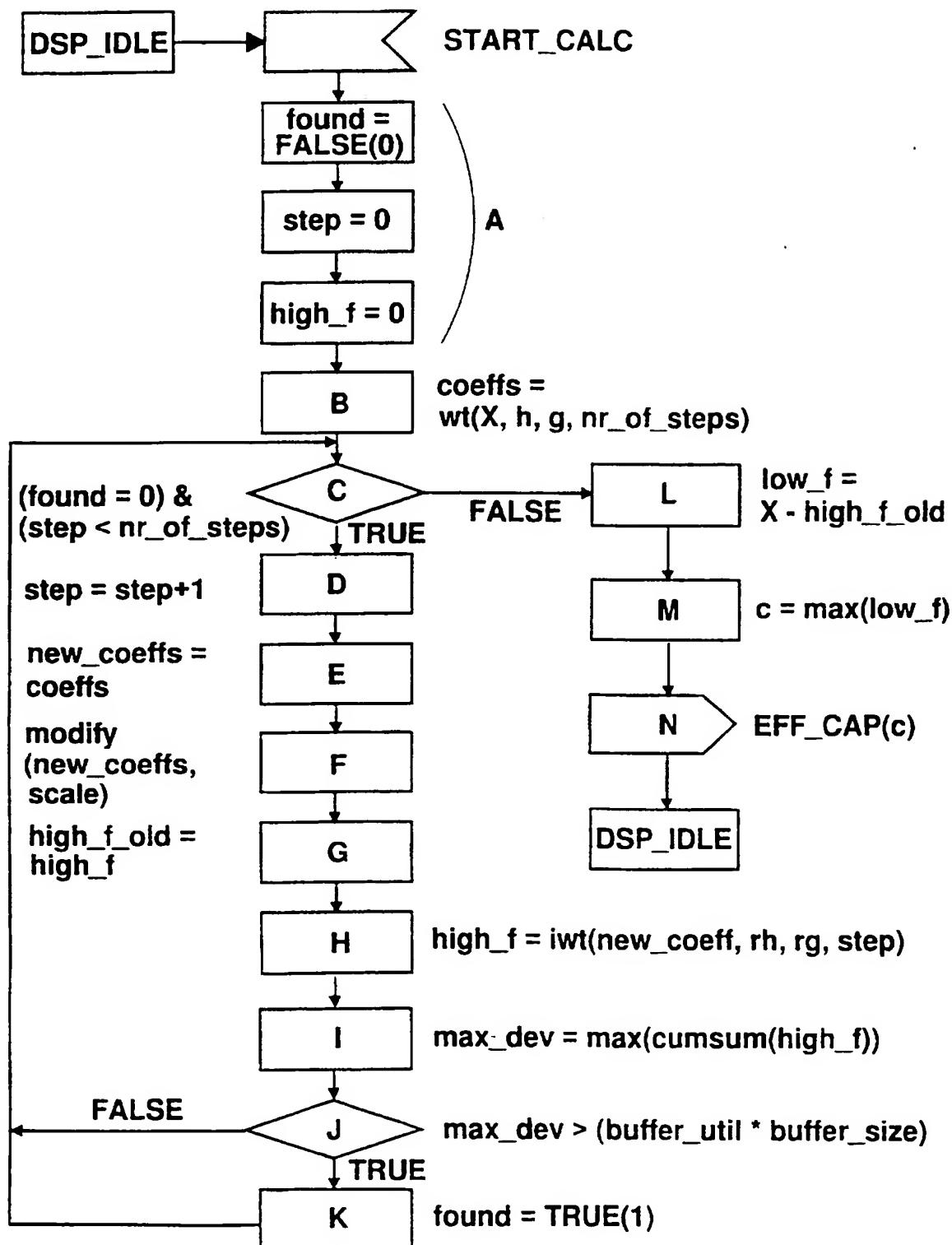


Fig. 8

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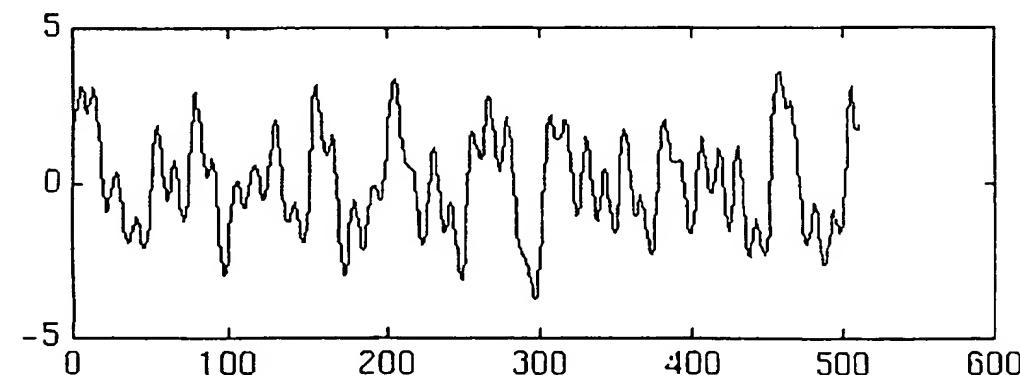
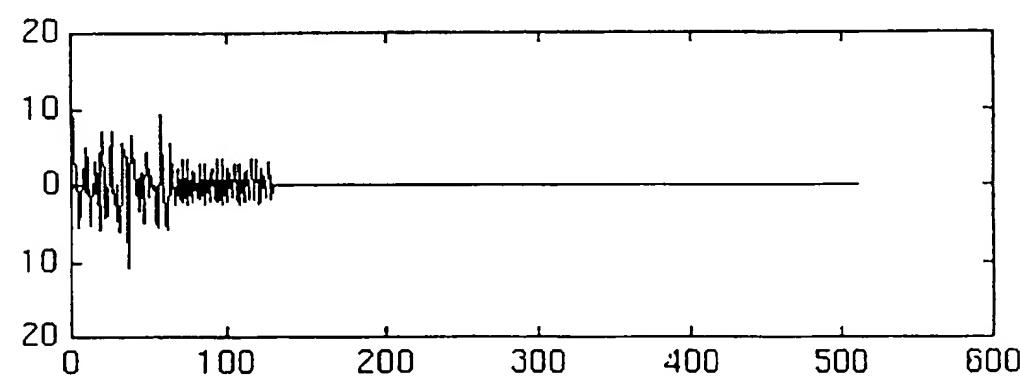
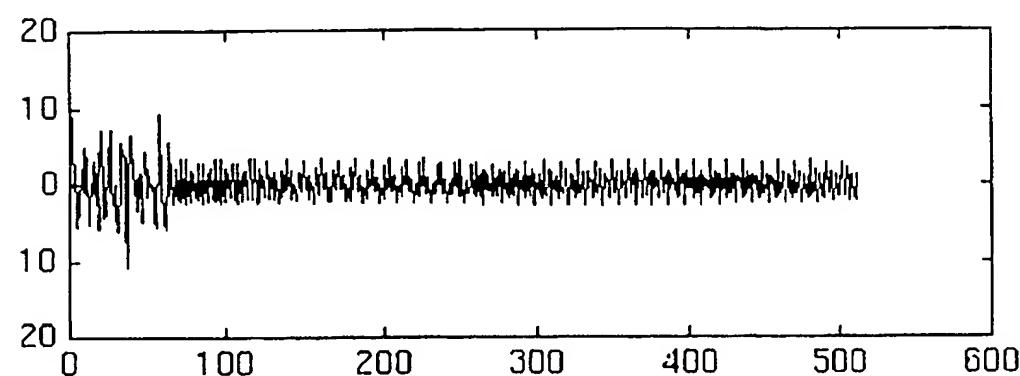
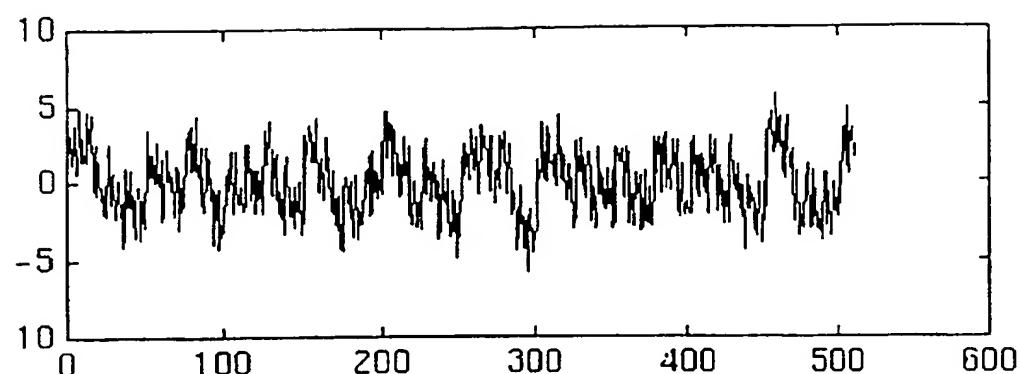


Fig. 9

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/IB 95/01122A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 H04Q11/04 H04L12/56

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 H04Q H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>PROCEEDINGS OF INFOCOM '95 - CONFERENCE ON COMPUTER COMMUNICATIONS, FOURTEENTH ANNUAL JOINT CONFERENCE OF THE IEEE COMPUTER AND COMMUNICATIONS SOCIETIES, BOSTON APR. 2 - 6, 1995,</p> <p>vol. 2, 2 April 1995, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS,</p> <p>pages 810-818, XP000580652</p> <p>DZIONG Z ET AL: "ESTIMATION OF AGGREGATE EFFECTIVE BANDWIDTH FOR TRAFFIC ADMISSION IN ATM NETWORKS"</p> <p>see paragraph 2; figure 2</p> <p>---</p> <p>-/-</p>	1,2,7,8, 12,13

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

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1

Date of the actual completion of the international search  13 December 1996	Date of mailing of the international search report  20.12.96
Name and mailing address of the ISA  European Patent Office, P.B. 5818 Patentaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	Authorized officer  Staessen, B

## INTERNATIONAL SEARCH REPORT

International Application No
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C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>DISCOVERING A NEW WORLD OF COMMUNICATIONS, CHICAGO, JUNE 14 - 18, 1992, vol. 2 OF 4, 14 June 1992, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 714-718, XP000326771 YUK T I ET AL: "SIMULATION OF ADMISSION CONTROL IN ATM NETWORK" see paragraph III.B - paragraph III.C ---</p>	1,2,7,8, 12,13
A	<p>ELECTRONICS &amp; COMMUNICATIONS IN JAPAN, PART I - COMMUNICATIONS, vol. 78, no. 10, 1 October 1995, pages 26-37, XP000546396 YOSHINORI KAWAMURA ET AL: "PARAMETER DESIGN OF DYNAMIC CONNECTION ADMISSION CONTROL IN ASYNCHRONOUS TRANSFER MODE NETWORKS" see paragraph 2.2 ---</p>	1-13
A	<p>US,A,5 359 593 (J.D DERBY ET AL.) 25 October 1994 cited in the application see abstract ---</p>	1-13
A	<p>DE,C,41 34 476 (TELENORMA) 6 May 1993 cited in the application see abstract -----</p>	3
1		

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

Inte Application No

PCT/IB 95/01122

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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		JP-A-	7087102	31-03-95

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DE-C-4134476	06-05-93	NONE
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